# REVIEW ARTICLE

# EGC Diagnosis of Paroxysmal Supraventricular Tachycardias in Patients without Preexcitation

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This review is aimed at discussing the diagnostic value of the different electrocardiographic criteria so far described in the differential diagnosis of the major forms of paroxysmal supraventricular tachycardias (PSVTs). The predictive value of different combinations of these independent electrocardiographic (ECG) signs in distinguishing atrioventricular reentrant tachycardias (AVRTs) through a concealed accessory pathway (AP) versus atrioventricular nodal reentrant tachycardias (AVNRTs) are discussed in detail. In addition, the adjunctive diagnostic value of simple, bedside clinical variables and their combinations to the ECG interpretation in differentiating both tachycardia mechanisms is also reviewed.

Supraventricular tachycardias denote all tachyarrhythmias that originate from supraventricular tissue or require it to be a part of the reentrant circuit. Paroxysmal supraventricular tachycardia (PSVT) denotes a clinical syndrome characterized by a rapid tachycardia with an abrupt onset and termination. While most supraventricular tachycardias are due to reentry, a small proportion is due to triggered activity or automaticity. Because of its widespread, immediate availability, and low cost, electrocardiographic (ECG) interpretation is of particular importance in the initial diagnosis of the major mechanisms of PSVT. However, a detailed cardiac electrophysiologic study is often needed to confirm the underlying mechanism and adequate ablation treatment. Variability in prevalence exists among the different supraventricular tachycardias mechanisms. While atrial flutter and atrial fibrillation are included in the list of supraventricular tachycardias, these arrhythmias have distinctly different mechanisms and management strategies and are not discussed in the current review. Based on a study of 1754 patients undergoing catheter ablation of 1856 SVTs (excluding atrial fibrillation, atrial flutter, and inappropriate sinus tachycardia) between 1991 and 2003, Porter et al found atrioventricular nodal reentrant tachycardia (AVNRT) to be the predominant SVT mechanism (56%), followed by atrioventricular reentrant tachycardia (AVRT) (27%), and atrial tachycardia (17%).[1] Atrial tachycardias are a minority in other previous consecutive series of cases with regular PSVT.[2–5] In addition, noninvasive maneuvers modifying atrioventricular (AV) nodal conduction are more frequently diagnostic in these patients. In fact, patients with atrial tachycardias without prior noninvasive diagnosis would constitute only 2.2% of our study population. Different catheter ablation strategies, outcomes and complications do exist in the two major PSVT mechanisms. A prior

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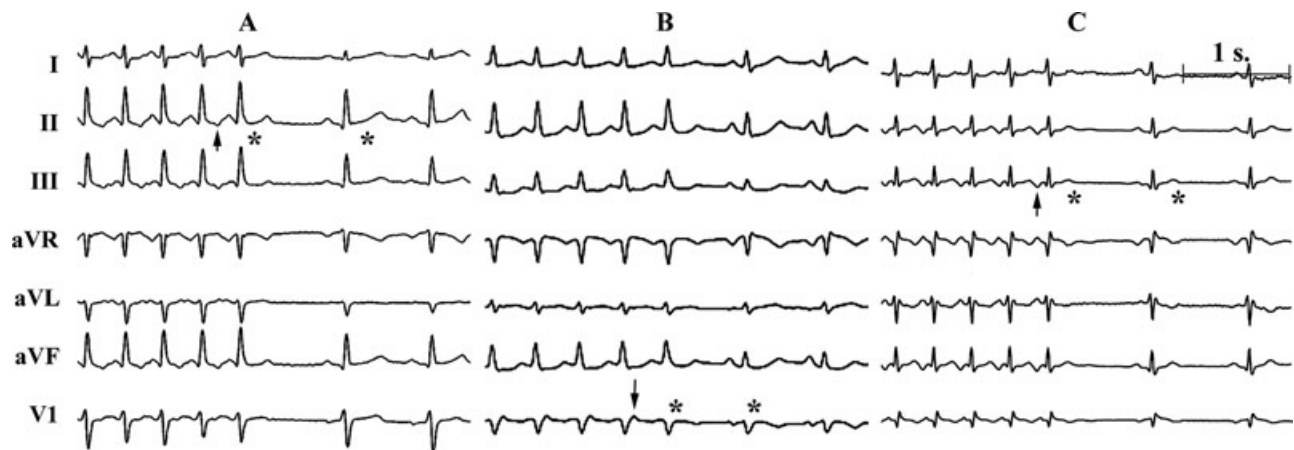
**Figure 1.** Identifying possible retrograde P waves. Careful comparison of repolarization morphologies permit probable retrograde P waves identification (arrows) and their disappearance (asterisks) with spontaneous tachycardia termination. (A) AVRT through concealed left free-wall AP; (B) spontaneous block in retrograde fast AV nodal pathway in a patient with common AVNRT (disappearance of pseudo-r′ wave in $V_1$); (C) spontaneous block in retrograde slow AVN pathway in uncommon AVNRT.

noninvasive presumptive diagnosis would therefore be valuable. The present review will focus on the ECG characterization and differential diagnosis of those main substrates of regular PSVT in patients without preexcitation in sinus rhythm. The adjunctive role of bedside clinical variables on that differential diagnosis is also discussed in detail.

## CLASSICAL ECG CRITERIA AND THEIR LIMITATIONS

Although resting 12-lead ECG should be examined for unusual P-wave morphologies or PR interval abnormalities (e.g., very short, or a sudden prolongation in the presence of a premature supraventricular complex), its main diagnostic usefulness for PSVT is threefold. First, the presence of overt preexcitation strongly suggests AVRT as the culprit tachycardia mechanism. Second, careful comparison with QRS morphology during tachycardia can be helpful in identifying subtle pseudo-r′/-s′ waves suggesting AVNRT. In addition, comparison of "pseudo" repolarization changes during tachycardia is of paramount importance in identifying subtle retrograde P waves, suggesting AVRT through a concealed AV accessory pathway (AP) (Fig. 1).

Major suggested ECG criteria in the differential diagnosis of two major mechanisms of PSVT (AVNRT vs AVRT) are summarized in Table 1.[2−15] Despite previous descriptions,[13] we and others have never seen pseudo-q waves as a reflection of early retrograde atrial activation in some AVNRT ECG tracings. In addition, measurements of RP intervals included in the algorithm of recent

**Table 1.** Suggested ECG Criteria for the Major Mechanisms of PSVT

| Favors AVNRT | Favors AVRT |
| --- | --- |
| Pseudo-r′ wave in $V_1$[2,4,5−7] | Visible retrograde P wave[2,4,5−7] |
| Pseudo-s wave in inferior leads | QRS alternans[2,5,8] |
| Pseudo-q wave in inferior leads[13] | ST-segment elevation in aVR[11] |
| Absence of positive ECG findings[5] | Marked repolarization changes in tachycardia[3,14,15] |
| Notch in aVL lead[12] | Lengthening of the tachycardia cycle length when bundle branch block occurs ipsilateral to the accessory pathway[13] |
| RP interval analysis: <70 ms[10] | RP interval >70 ms[10] |
| Response to ATP test[9] | Response to ATP test[9] |

Differential diagnosis when RP interval >70 ms does include AVRT, atypical AVNRT and atrial tachycardia. See text for discussion and further details.
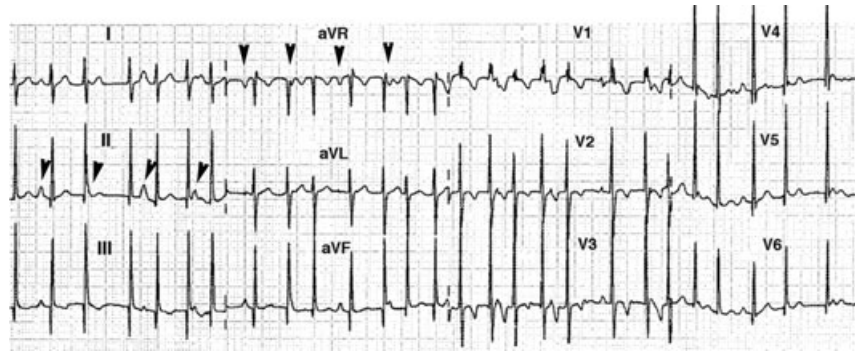
**Figure 2.** Automatic focal junctional tachycardia in a 2-year-old infant showing clear atrioventricular dissociation in an otherwise narrow QRS complex tachycardia. Irregular firing of the automatic parahissian focus explained the irregularity of R–R intervals.

guidelines ultimately rely on the identification of visible P waves during tachycardia.[10] Surprisingly, other important ECG findings suggesting AVNRT such as the presence of pseudo-r′ wave in $V_1$ are commented but excluded from that diagnostic algorithm. When RP > PR, the differential diagnosis will encompass atrial tachycardia, junctional reciprocating tachycardia using a slow conducting AP (Coumel type) or uncommon forms of AVNRT (slow–fast). ECG features of the last two mechanisms are exactly the same, including RP > PR interval with an abnormal P-wave axis (negative P waves in leads II, III, aVF, and $V_4$–$V_6$). However, in contrast to atypical AVNRT, onset of the permanent junctional reciprocating tachycardia is not usually preceded by a prolongation in the PR interval. Patients with focal junctional tachycardia may mimic the pattern of slow–fast AVNRT and may show AV dissociation and/or marked irregularity in the junctional rate (Fig. 2). As a matter of fact, sinus tachycardia is part of the differential diagnosis of these long RP tachycardias. Moreover, mapping of activation indicates that at faster rates, the sinus node impulse originates from more superior areas of the crista terminalis leading to a subtle change of P-wave morphology during sinus tachycardia (Fig. 3). Consequently, this morphology change should not be interpreted as sign of possible atrial tachycardia.

P-wave polarity during an orthodromic tachycardia may help in localizing the AP: a negative P wave in lead I suggests the atrial insertion of the pathway is in the left free wall, while negative P waves in the inferior leads suggest it is in the posteroseptum or upon an inferior right or left atrial insertion site. In a prior study,

however, the greatest source of intraobserver variability was the identification of retrograde P waves.[7] In addition, it is often difficult to discern the morphology of the P wave during tachycardia. Nevertheless, a reliable ECG algorithm derived from the analysis of retrograde P waves during tachycardia has been developed for the differential diagnosis between AVNRT and AVRT.[16] Alternation of R-wave voltage amplitude (>0.1 mV) during regular PSVT was initially associated with the presence of AVRT[8] and later reported as a mere consequence of faster heart rate in these tachycardias.[17] Several mechanisms have been postulated to explain the presence of QRS alternans. Their corresponding operative role on this ECG phenomenon remains to be clarified. As stated below, the marginal diagnostic power of this ECG finding in discriminating major PSVT mechanisms is emphasized when its occasional transient nature is observed in some cases (Fig. 4).

It is well known that a bedside test of adenosine triphosphate (ATP) injection during sinus rhythm identifies patients with palpitations who are likely to have AVNRT or AVRT with a high positive predictive value (93%; sensitivity: 71%). Its negative predictive value was 37% (specificity: 76%). A positive ATP test suggestive of dual AV nodal physiology was defined when a >50 ms PR interval increment or shortening in two consecutive sinus beats was observed or the drug elicited AV nodal echoes or AVNRT. Similarly, the occurrence of AV reentry echo beats or AVRT was considered as indicative of a positive ATP test suggestive of concealed AP. The occurrence of 2nd–3rd AV block without any of the above criteria despite incremental administration of up to 60 mg of ATP were considered
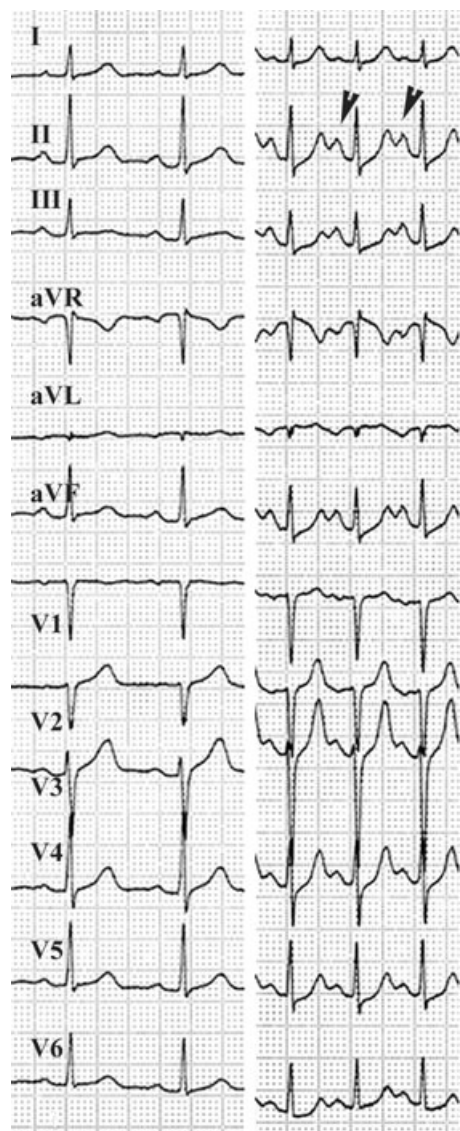
**Figure 3.** Subtle morphology changes in sinus P waves are observed during sinus tachycardia (right). At fast rates, the P wave in the inferior leads is taller because the location of the sinus pacemaker is higher in this patient with a postural orthostatic tachycardia syndrome (POTS).

negative or inconclusive ATP tests, respectively.[9] In our opinion, however, this ATP test has not achieved widespread use in the everyday clinical practice.

Prevalences of four major ECG criteria in the differential diagnosis of AVNRT and AVRT obtained from 500 consecutive ECG tracings are detailed in Figure 5. Significant univariate differences were observed when these four criteria were compared between both tachycardia mechanisms.[5] Anyway,

the accuracy of ECG interpretation in differentiating AVNRT versus AVRT through a concealed AP is only modest: 68% of correct classifications, in our experience (Fig. 6A). A subjective ECG diagnosis of AVNRT has a high positive predictive value due to, at least in part, current high prevalence of this tachycardia mechanism (about 70%).

## Independent Diagnostic Value of Major ECG Criteria

The presence of pseudo-r′ deflection in $V_1$ and/or pseudo-s waves in inferior leads (adjusted OR: 17), an identifiable P wave after the QRS complex (adjusted OR: 0.18), and QRS alternans (adjusted OR: 0.4) were selected by stepwise multiple logistic regression analysis as independent predictors for the diagnosis of AVNRT (vs AVRT) in our derivation group of 300 patients.[5] Figure 7 shows the predicted probabilities obtained from the derivation group for both tachycardia mechanisms depending on every combination of selected ECG parameters.[5] Diagnostic probabilities >75% were found for nearly 70% of our patients. The presence of pseudo-r′($V_1$)/-s (inferior leads) waves as isolated positive findings (21% of our series) identified an AVNRT with a predicted probability for a correct diagnosis of 98%. Interestingly, a diagnostic probability for AVNRT greater than 76% is predicted when all selected ECG criteria are lacking, thus highlighting the value of negative ECG findings. The presence of atypical forms of AVNRT with identifiable retrograde P waves may explain the moderate predicted probability of this ECG finding for a correct AVRT diagnosis (67%). We consider atypical AVNRT as those with VA intervals >100 ms in high right atrium. Of note, repolarization abnormalities during tachycardia were not selected as independent covariates of the tachycardia mechanism. Previous univariate analysis have shown that the presence of certain repolarization changes during narrow QRS complex tachycardia may be a useful adjunct for determining arrhythmia mechanism.[3,14,15] A distinct pattern of retrograde atrial activation during AVRT combining a longer ventriculoatrial interval and a retrograde atrial activation of longer duration overlapping ST segment can explain this finding.[3] It is therefore possible that the presence of clearly identifiable retrograde P wave on 12-lead ECG could offset the diagnostic value of associated repolarization changes, thus preventing its predictive influence in the multivariate logistic model.[5]
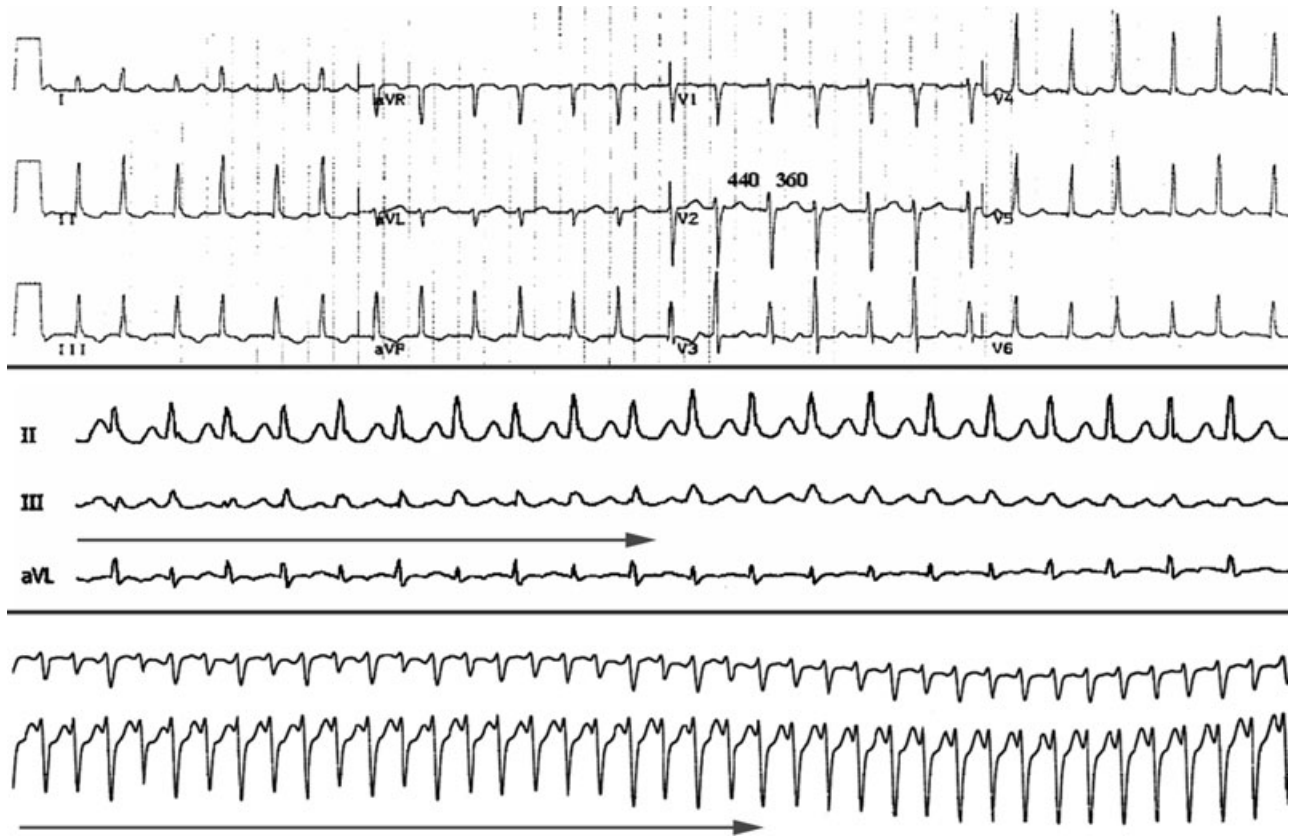
**Figure 4.** Three examples of QRS alternans in AVNRT patients. Top panel: QRS alternans associated with alternative R–R intervals. Middle and bottom panels: transient QRS alternans with spontaneous disappearance (end of arrows) without discernible changes in R–R intervals.
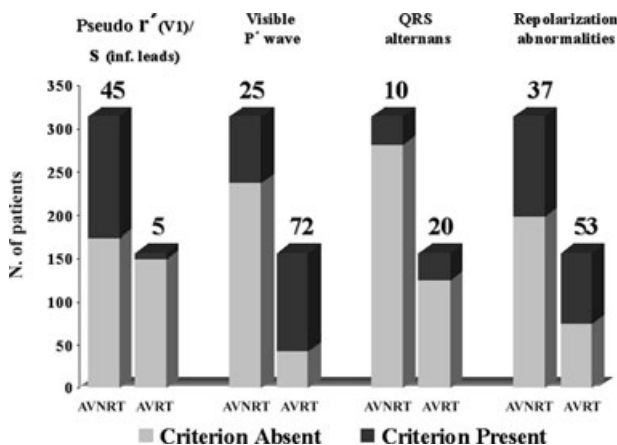


**Figure 5.** Prevalences and univariate comparisons of major ECG criteria for AVNRT and AVRT through a concealed AP (figures are percentages of recordings with positive ECG criterion). Data from 500 consecutive ECG recordings. P < 0.01 for every criterion comparison. Abbreviations as in Figure 1.

## DIAGNOSTIC VALUE OF BEDSIDE CLINICAL VARIABLES

We recently demonstrated that age at the onset of symptoms, sensation of rapid regular pounding in the neck during tachycardia episodes, and female sex are the only significant clinical variables in distinguishing AVNRT versus AVRT in patients without preexcitation in sinus rhythm.[18] Interestingly, these three simple clinical variables allow us to construct a logistic regression model to predict the presence of an AVNRT (vs an AVRT) with a diagnostic validity that compared positively with that obtained using blinded ECG interpretation (Fig. 6B). These variables were selected by the logistic model as predictors of the tachycardia diagnosis when the ECG interpretation was included in the analysis (C statistic = 0.81 vs 0.75 with clinical variables alone; P = 0.003). Their consideration therefore adds significant diagnostic
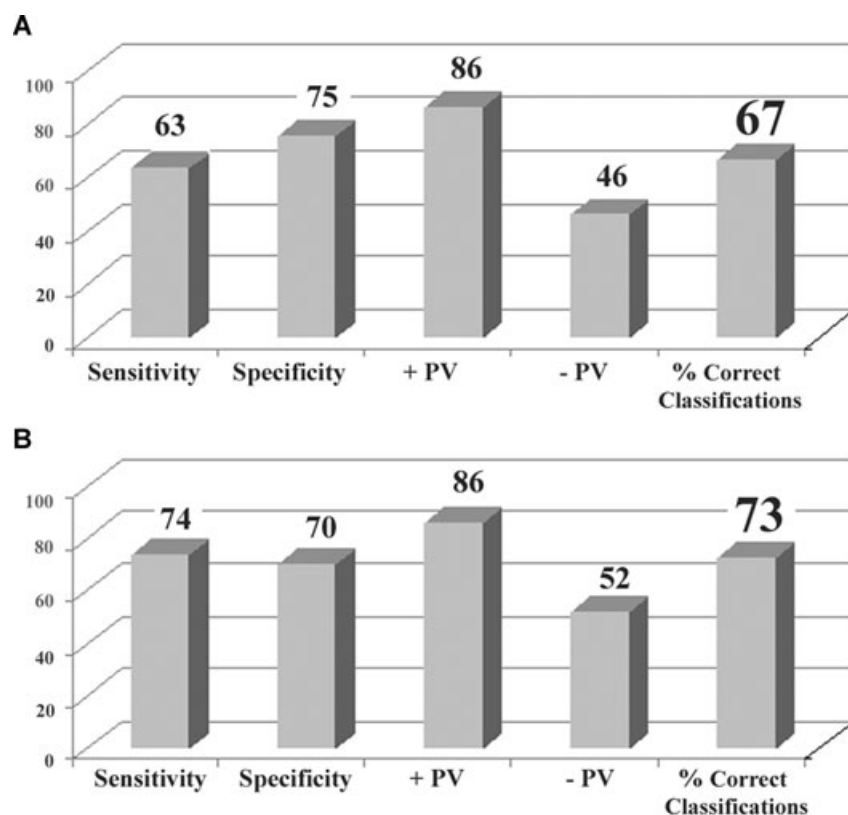
**Figure 6.** (A) Diagnostic yield of subjective ECG interpretation in the differential diagnosis of AVNRT versus AVRT from 420 consecutive ECG tracings in patients without preexcitation during sinus rhythm who underwent invasive diagnosis. Sensitivity, specificity, and predictive values for a subjective ECG diagnosis of AVNRT (vs AVRT) are shown. (B) Corresponding values from a logistic regression model including bedside clinical variables to predict a correct AVNRT diagnosis (vs AVRT). Figures are percentages. See text for discussion.

**Table 2.** Multivariate Regression Results for the Diagnosis of AVNRT (vs AVRT)

| Selected Clinical Variables[a] | OR (95% CI) | Wald $\chi^2$ | P Value |
|---|---|---|---|
| Age at onset of symptoms | 1.27 (1.17–1.36)[c] | 39 | 0.0001 |
| Palpitations in the neck | 4.36 (2.53–7.52) | 28 | 0.0001 |
| Female sex | 2.4 (1.48–3.91) | 12.6 | 0.0001 |
| Selected clinical variables and ECG diagnosis[b] | | | |
| ECG interpretation[d] | 4.2 (2.5–7.08) | 29.3 | 0.0001 |
| Age at onset of symptoms | 1.24 (1.15–1.34)[c] | 30.9 | 0.0001 |
| Palpitations in the neck | 4.27 (2.4–7.5) | 24.7 | 0.0001 |
| Female sex | 2.3 (1.4–3.8) | 9.9 | 0.002 |

Analysis from 430 consecutive patients with invasive, definite tachycardia diagnosis.
[a]Constant: $\exp(\beta) = 0.209$ (SE = 0.31), P = 0.0001. Hosmer–Lemeshow's goodness-of-fit test: P = 0.804.
[b]Constant: $\exp(\beta) = 0.128$ (SE = 0.346), P = 0.0001. Hosmer–Lemeshow's goodness-of-fit test: P = 0.355.
[c]Per 5-year increase.
[d]ECG subjective diagnosis suggesting AVNRT (vs AVRT).
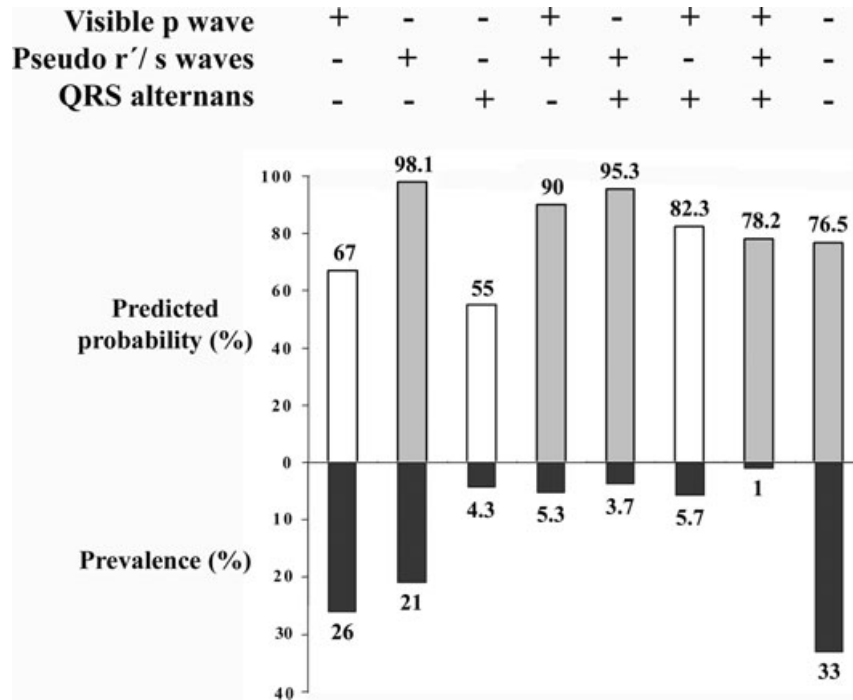
**Figure 7.** Predicted probabilities from a logistic regression model for the diagnosis of AVNRT (gray bars) or AVRT (white bars) depending on every combination of selected ECG criteria (present: +; absent: −). The corresponding prevalences of every combination of ECG criteria in our study group are shown in dark gray bars. The predictive value of QRS alternans as an isolated ECG finding was considered as indeterminate. Figures are percentages. (From González-Torrecilla E et al. Independent predictive accuracy of classical electrocardiographic criteria in the diagnosis of paroxysmal atrioventricular reciprocating tachycardias in patients without preexcitation. Europace 2008;10:624–8. With permission).

information to the ECG. Age at the onset of symptoms emerged as the strongest predictor of AVNRT (vs AVRT) (Table 2). A cross-validation of the logistic model including ECG interpretation and those clinical variables has been performed from 100 further PSVT patients (68 AVNRT, 32 AVRT). An acceptably low shrinkage prediction factor was calculated (7%). Figures 8 and 9 show the predicted probabilities for the diagnosis of AVNRT or AVRT depending on every combination of selected clinical variables (Fig. 8) and those diagnostic probabilities when the ECG interpretation is included in the model (Fig. 9). Adjusted diagnostic probabilities >70% and >80% were found in 66% and 54% of our patients using different combinations of these clinical variables. When ECG interpretation was included in the analysis, these diagnostic probabilities were found in 71% and 52% of the patients, respectively. In fact, the presence of positive findings in ≥2 of those clinical variables strongly favors

(≥80% of predicted probability) a correct AVNRT diagnosis. Therefore, these clinical findings might be useful when ECG information is lacking or limited, such as in ambulatory Holter monitoring. That predicted probability increases to ≥90% when ≥2 positive clinical findings are present in conjunction with a presumptive ECG diagnosis of AVNRT.

## ECG and Clinical Data in Specific Subgroups of PSVT Patients

### Patients with Atypical AVNRT

Almost one third (31%) of incorrect classifications as AVRT (false-negative diagnoses) derived from our logistic predictive model were in patients with atypical forms of AVNRT (Fig. 10). This subgroup of atypical AVNRT patients had a lower prevalence of a significant predictive covariate such as the presence of rapid regular pounding in the neck during tachycardia episodes as a
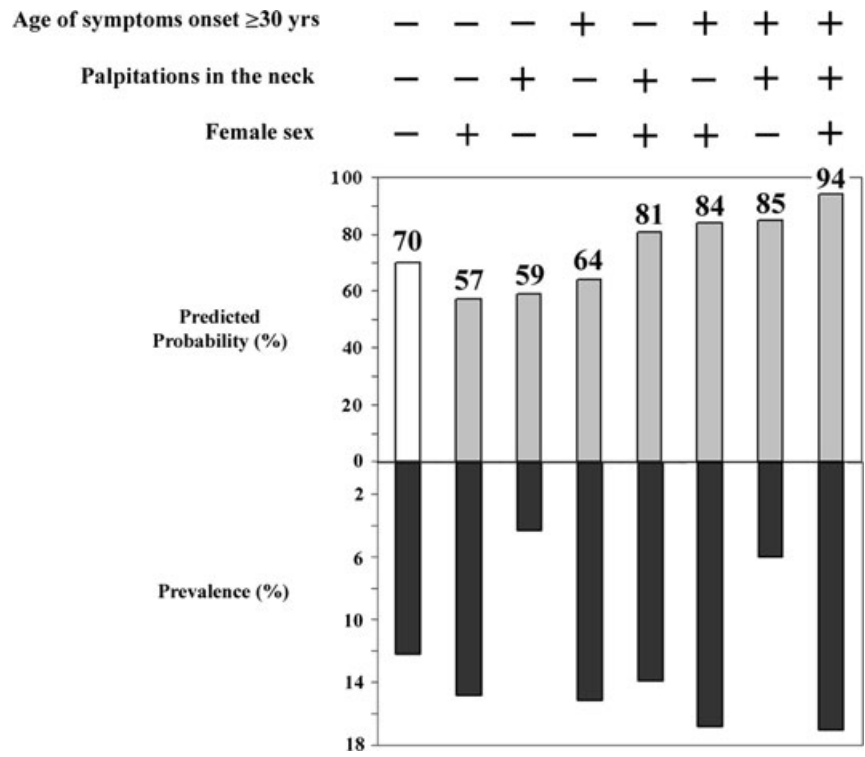
**Figure 8.** Predicted probabilities for the diagnosis of AVNRT (gray bars) or AVRT (white bars) depending on every combination of selected clinical covariates (present: +; absent: −). The corresponding prevalences of every combination of clinical criteria are shown in dark gray bars. For reasons of simplicity, age at symptoms onset was dichotomized using the selected cut-off value of ≥30 years. Figures are percentages.

result of longer VA intervals (Fig. 11). The latter might partially offset the predictive accuracy provided by clinical covariates in the total study group. The ECG characterization of these AVNRT forms is scarce. Short series of slow–slow AVNRT suggest that differences of the RP' intervals between $V_1$ and the inferior leads in the tachycardia ECG (>20–30 ms) were useful for the differential diagnosis of these atypical AVNRT from patients with an AVRT using concealed posteroseptal APs.[19] In prior study, when the difference of RP' intervals in leads $V_1$ and III was >20 ms, a posterior-type (slow–slow) AVNRT could be differentiated from AVRT through a posteroseptal AP with a sensitivity, specificity and positive predictive value of 71%, 87%, and 75%, respectively.[16] Further analyses are needed from larger atypical AVNRT series.

**Patients without Positive ECG Criteria during PSVT**

In our experience, up to 73% of PSVT without identifiable major ECG criteria were typical forms of AVNRT. Classically, ECG interpretation of these patients has been challenging. Interestingly, the presence of neck palpitations appeared as the only significant predictive variable for an AVNRT diagnosis in our 134 patients without positive ECG criteria during tachycardia (OR: 7.5). This clinical covariate led to 77.5% correct classifications as compared with only 60% correct classifications by ECG interpretation in this subset of patients (P < 0.001). Sensitivity, specificity, and positive and negative predictive values of that clinical finding for identifying AVNRT in this subgroup of patients were 52%, 90%, 95%, and 36%, respectively.[18]

## ECG IN PAROXYSMAL FOCAL ATRIAL TACHYCARDIAS

ECG localization of macroreentrant atrial tachycardias is complex and influenced by altered atrial anatomy, prior surgical incisions, and conduction abnormalities of the atrial wavefront. As previously stated, ECG characterization of different atrial
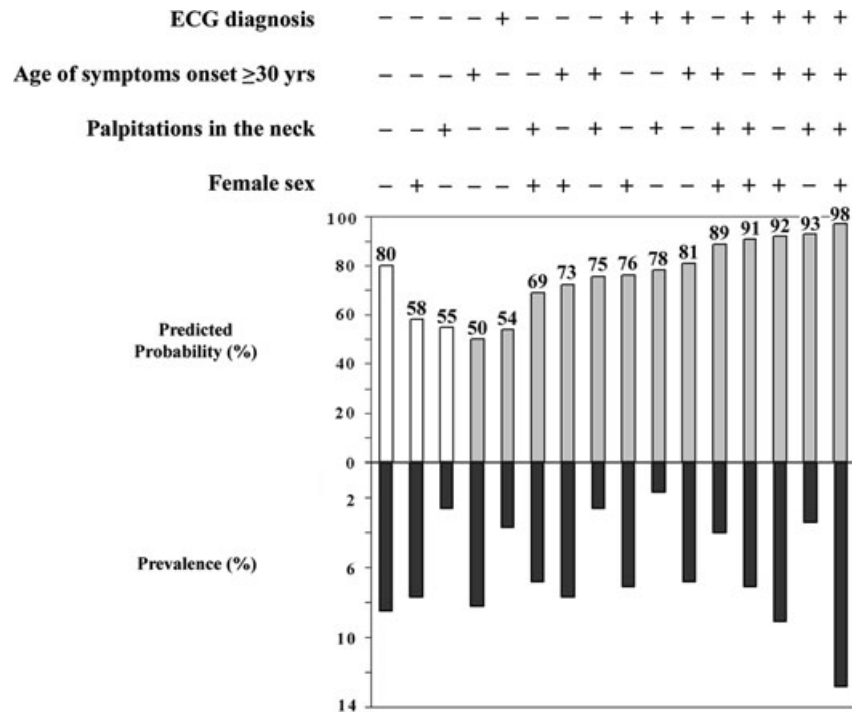
**Figure 9.** Predicted probabilities for the diagnosis of AVNRT (gray bars) or AVRT (white bars) depending on every combination of selected clinical covariates when ECG presumptive diagnosis is included in the logistic model. ECG is + or – indicating a diagnosis of AVNRT or AVRT, respectively.

flutter forms is beyond the scope of this review. Although focal atrial tachycardia is the least common type of PSVT, the surface ECG is nevertheless very helpful in directing mapping to specific areas of interest. This tachyarrhythmia is characterized by P waves separated by an isoelectric interval in all ECG leads. The extensive literature correlating P-wave morphology and the site of atrial focus has developed several ECG algorithms for localizing atrial ectopy.[20–22] Although these algorithms are useful, several limitations of ECG P-wave localization have to be commented. First, there is a considerable overlap in P-wave morphology reflecting the limited spatial resolution of the P wave estimated at 17 mm in a pace mapping study. Second, P-wave morphology analysis must be made on atrial deflections that are not partially obscured by the T wave or QRS complex during tachycardia. Third, close anatomical proximity and the presence of interatrial electrical connections may compound the difficulty in differentiating between different atrial areas in some cases. Finally, these algorithms have been based on analysis of ECG tracings from patients without structural heart disease, atrial di-

latation, prior surgery, or extensive atrial ablation. In addition, most of these algorithms are not easy to memorize. However, six simple statements are well worth retaining:

(a) A positive or negative–positive biphasic P wave in $V_1$ has 93–100% sensitivity, 81–88% specificity, 76–87% positive predictive value, and 94–100% negative predictive value for a left atrial origin.[20,22]

(b) Superior/mid crista terminalis is the most common site for right atrial tachycardia. A crystal origin can be predicted by the presence of a positive–negative $V_1$ P wave (or positive $V_1$ during tachycardia and sinus rhythm), positive leads I and II, and negative aVR.

(c) A common feature of tricuspid annular tachycardias is the presence of an inverted P wave in $V_1$ and $V_2$ with late precordial transition to a positive appearance.

(d) Deeply negative P waves in inferior leads, usually isoelectric-positive or negative–positive P waves in $V_1$ and positive in both aVL and aVR, characterize a coronary ostium origin.
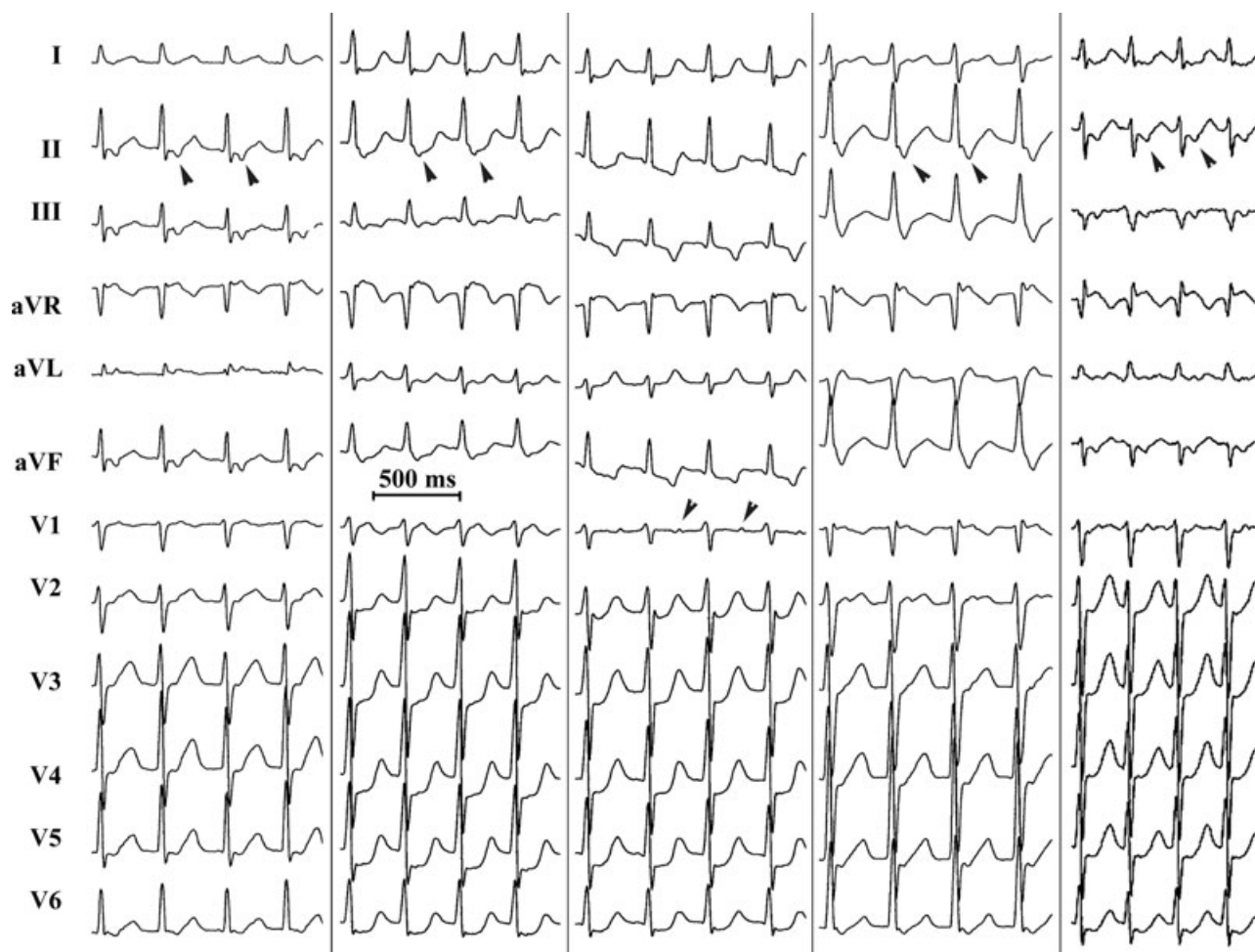
**Figure 10.** Twelve-lead ECGs from five patients with atypical forms of AVNRT misclassified as AVRT after subjective ECG interpretation of identifiable P waves (arrowheads).

(e) For right perinodal and right septal foci, an isoelectric P wave in $V_1$ is helpful when present. In Kochs triangle foci, the P-wave duration in the inferior leads was shorter than during sinus rhythm. Left septal foci may demonstrate either a positive P wave in $V_1$ or a biphasic negative–positive appearance. In our experience, the septal region is the most unpredictable location using current ECG criteria.[23]

(f) Pulmonary vein ostia are the most common sites for left atrial focal tachycardias. Their universal finding is a positive P wave in $V_1$ and across the precordial leads. A P-wave negative in aVR and negative/isoelectric in aVL is common. Left-sided vein foci have a broader, notched P wave in $V_1$ and inferior leads compared with right-sided veins that usually have a positive P wave in lead I.

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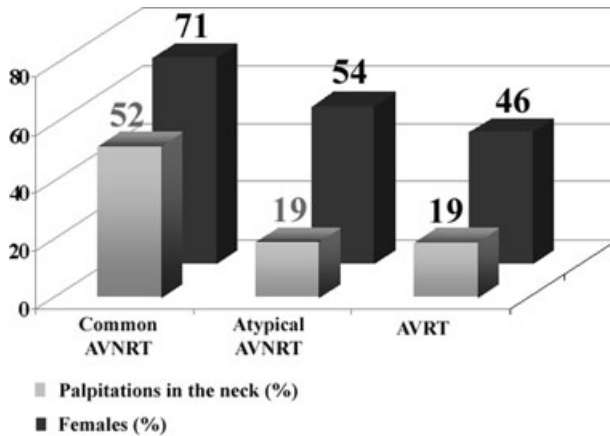
**Figure 11.** Gender differences and prevalences of neck palpitations during tachycardia episodes in patients with common AVNRT, atypical AVNRT (slow–slow and uncommon AVNRT forms) and AVRT. The percentage of atypical AVNRT patients referring palpitations in the neck during tachycardia episodes was quite similar to those with AVRT (19%). Age at the onset of symptoms was higher in atypical AVNRT than in AVRT patients (41 ± 19 vs 25.5 ± 16 years, respectively). Figures are percentages.

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